U.S. PATENT APPLICATION

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Invention: A PORTABLE MULTI-BAND COMMUNICATION DEVICE, AND A
METHOD FOR DETERMINING A CHARGE CONSUMPTION THEREOF

SPECIFICATION

A PORTABLE MULTI-BAND COMMUNICATION DEVICE, AND A METHOD FOR DETERMINING A CHARGE CONSUMPTION THEREOF

Technical Field

The present invention relates to portable multi-band communication devices having a power amplifier, a battery for supplying power to the power amplifier, and a controller which is arranged to control an output power level of the communication device by generating a digital control signal for the power amplifier. More specifically, the invention is directed at providing portable multi-band communication devices with improved functionality for charge consumption determination to be used for estimating remaining battery capacity. The invention also relates to a method for such charge consumption determination.

Prior Art

Users of portable battery-powered communication devices are dependent of a fully functional device. More specifically, the users need to know exactly for how long their devices will remain functional, until the electric energy stored in the battery has been consumed and the battery has to be recharged. This is particularly true for users of mobile telephones. Hence, for the rest of this document a mobile telephone is used, in a non-limiting sense, for exemplifying the inventive portable communication device and method.

In order to determine a precise estimation of the remaining operational time of the mobile telephone, the user needs an accurate and well-functioning battery capacity indicator or "fuel gauge". FIG 1 illustrates a schematic mobile telephone 1 having a display 6, on which an icon 13 is presented as a battery capacity indicator. As shown in FIG 1, the battery icon 13 indicates that approximately 25% remains of the initial battery charge.

The mobile telephone 1 may have further display facilities for determining and indicating an estimated remaining time of operation, i.e. an estimation of the time left until the battery will have to be recharged.

Determining the remaining battery capacity basically includes two separate current measurements; one measurement for the current flowing into the battery (charging) and one measurement for the current consumed from the battery (discharging).

The charging current is often relatively easy to measure. A microprocessor (CPU) may read an A/D-converted signal, which is directly proportional to the current flowing through a small resistor. Since the microprocessor controls the charging process, it will also have access to all relevant data for calculating the total current, that has been supplied to the battery during a certain period of time.

Measuring the discharge current or current consumption, on the other hand, is much more difficult, particularly for advanced telephones with complex functionality and many operating modes. Traditionally, discharge current is measured by calculating the expected current consumption, when the telephone is in different operating modes. Earlier mobile telephones basically had two operating modes only; talk mode and standby mode. For such mobile telephones, the current consumption in talk mode and standby mode, respectively, was measured once in a test laboratory environment and stored in memory in the telephone as a respective predetermined consumption value. In operation, the telephone would keep track of the time spent in talk mode and in standby mode, respectively, and subsequently calculate the total amount of current consumed from the battery by multiplying the respective operational times with the predetermined consumption values.

Such an approach is disclosed in US-A-5 248 929, wherein a microprocessor in the mobile telephone regularly executes an interrupt-driven software routine (once every 100 ms), during which the momentary operational mode is

5   determined. The predetermined consumption values are read from memory, and the resulting charge consumption value is added to an accumulated value, which in turn is used for determining remaining battery capacity and operational time in talk mode and standby mode.

10   Although providing an acceptable charge consumption estimation for a simplified scenario with only two operating modes, the prior art approach described above has not proven applicable to more advanced telephones having a plurality of operational modes. For instance, the

15   charge consumption of a contemporary TDMA ("Time Division Multiple Access") telephone does not only depend of whether the telephone is in standby mode or talk mode; the charge consumption is affected by at least the following conditions in standby mode and talk mode, respectively:

20   <u>Standby mode</u>
- Number of neighboring base stations
- Paging frequency
- Backlight
- LCD icon mode on/off

25   - Location update frequency
- Top indicator
- Accessory connected/disconnected

<u>Talk mode</u>

30   - Output power
- Backlight
- Band (900/1800/1900 MHz)
- HR/FR/EFR (Half Rate/Full Rate/Enhanced Full
  _ Rate), i.e. speech encoder mode

35   - HF algorithm

- DTX/no DTX (Discontinuous Transmission)
- DRX/no DRX (Discontinuous Reception)
- Accessory connected/disconnected

Of the above, the output power in talk mode has a
5   major influence on the battery charge consumption. For a
telephone which operates in more than one frequency band,
i.e. a multi-band telephone, the output power is different
for different frequency bands. Conclusively, in view of
all the other parameters, which will affect the charge
10   consumption, a multi-band telephone will have a very large
number of different operating modes. Previously known
approaches fail to provide accurate and still efficient
charge consumption determination, and consequently there
is an urgent need for an alternative way of determining
15   battery charge consumption for a multi-band telephone.

Summary of the Invention

The object of the present invention is to provide a
new and substantially improved way of determining battery
20   charge consumption for a portable multi-band communication
device, such as a mobile telephone.

Generally, the object has been achieved by the
following inventive understandings. Firstly, the aforesaid
problem that a multi-band communication device inherently
25   has a very large number of different operating modes,
thereby making conventional charge consumption estimation
both complex and inaccurate, can be avoided by making use
of an already existing power amplifier control facility.
More specifically, whenever voice or data is to be trans-
30   mitted from a multi-band telephone, the transmission has
be carried out at correct output power level, which - as
described above - depends on the frequency band used.
Correct output power is obtained by the controller by
regulating an analog control signal to the power amplifier
35   module. To this end, the controller calculates a proper

digital (e.g. hexadecimal) value (DAC value), which is converted by a D/A (digital-to-analog) converter into the analog control signal to the power amplifier.

Now, according to the invention, since the power amplifier consumes a major part of the total current drawn from the battery in talk mode, the charge consumption of the power amplifier may be accurately predetermined for different DAC values, preferably by way of measurements in a test laboratory environment, before the telephone is initially being used. Consequently, these predetermined charge consumption values will be associated with a respective one of all possible DAC values and will be prestored in a memory of the telephone.

Furthermore, according to the invention, these prestored charge consumption values are used by the controller for keeping record of an accumulated charge consumption value between subsequent battery chargings. This is possible, since the controller is also responsible for generating the DAC values whenever a transmission is to take place. Therefore, the controller will always have access to the momentary DAC value and may read a corresponding prestored charge consumption value to be added to the accumulated value.

The invention is particularly well adapted for a TDMA telephone, which uses different control pulses or "strobes" for switching on and off different radio circuits, e.g. power amplifier, filters and synthesizer, as well as other electronic circuits, e.g. A/D converters. The strobes are all completely controlled by the microprocessor in such a way, that the telephone may send and receive in the correct timeslot.

More specifically, the object above has been achieved by a portable communication device and a method of determining the charge consumption thereof according to the appended independent patent claims. Other objects,

features and advantages of the present invention will appear from the following detailed disclosure, from the attached drawings as well as from the dependent claims.

Brief Description of the Drawings

A preferred embodiment of the present invention will now be described in more detail, reference being made to the accompanying drawings, in which:

FIG 1 is a schematic front view of a mobile telephone having a graphical indicator for remaining battery capacity,

FIG 2 is a schematic block diagram of the principal electronic and electric components of the mobile telephone shown in FIG 1,

FIG 3 schematically illustrates a hardware implementation according to the first embodiment,

FIGs 4 and 5 are flow charts illustrating a software implementation according to the first embodiment,

FIGs 6-8 illustrate a second embodiment of the present invention and

FIGs 9-11 illustrate a third embodiment of the invention.

Detailed Disclosure of Embodiments

Some embodiments of the present invention will now be described in detail by referring to a mobile telephone 1 shown in FIG 1. However, as already mentioned, the present invention is equally applicable to all other portable communication devices, which fall under the definitions in the independent claims.

The ·mobile telephone 1 is a cellular GSM TDMA telephone and comprises an antenna 2, a top indicator 3 for indicating operational status, a speaker 4, volume adjustment buttons 5, a graphical display 6, a set of keys in a keypad 7 and a flip 8, which is pivotally mounted to a

telephone housing 11 by means of a hinge 12. The flip 8
has a speech opening 9 for receiving vocal acoustic energy
from the user of the telephone. The acoustic energy is
transmitted through the flip 8, via an internal sound
5   guiding channel not shown in the drawing, to an internal
microphone (not shown) in the telephone housing 11.

The display 6 comprises a signal strength indicator
14, a telephone operator indicator, a date indicator 15
and a remaining battery capacity indicator 13.

10   The principal electronic circuitry of the mobile
telephone is illustrated in FIG 2. From an overall point
of view, the circuitry comprises an antenna 200, a radio
block 210, a channel encoding/decoding block 220, a speech
encoding/decoding block 230, a control block 240, a micro-
15   phone 250, a speaker 260 and a battery 270. Except for the
control block 240, all blocks 200, 210, 220, 230, 250, 260
and 270 have a design and structure, which are well-known
and typical for a TDMA telephone commonly available on the
market. Therefore, these blocks are only given a brief
20   description below; the detailed architecture thereof is
well-known to the skilled person.

The speech encoding/decoding block 230 comprises a
speech encoder 232, an input of which is connected to an
output of the microphone 250 and an output of which is
25   connected to an input of a channel encoder 222 in block
220. An output of the channel encoder 222 is connected to
an input of a transmitter 214, which is part of the radio
block 210. An output of the transmitter 214 is connected
to the antenna 200. Hence, in a well-known way the
30   microphone 250 receives a spoken audible input from a user
and converts it into a corresponding electric signal,
which is supplied to the speech encoder 232. The speech
encoder 232 applies either HR, FR or EFR speech encoding
to the signal and supplies the result to the channel
35   encoder 222, which performs channel encoding according to

GSM TDMA standard. The output of the channel encoder 222 is fed to the transmitter 214, which comprises various electronic circuits, such as amplifiers, filters and mixers. A power amplifier 216 controls the output power
5   level of the transmitter 214. In turn, the power amplifier 216 is controlled by an analog control signal Pwr Ctrl, which is supplied by the control block 240 as a digital signal (DAC value) and is converted into the analog Pwr Ctrl signal by a D/A (Digital-to-Analog) converter 218, as
10   will be described in more detail below. The output of the transmitter 214 is a high-frequency TDMA signal in any available frequency band (such as 900 or 1800 MHz), and this signal is supplied to the antenna 200 and emitted into open air as electromagnetic waves propagating from
15   the antenna 200.

Correspondingly, an incoming TDMA signal is received at the antenna 200 and processed by a receiver 212 in the radio block 210. Basically, the operation of the receiver 212 is the inverse of that of the transmitter 212. An
20   output of the receiver 212 is decoded in a channel decoder 224 in block 220 and is furthermore decoded by a speech decoder 234 in block 230. The output thereof is supplied to the speaker 260, which converts the electric signal into acoustic soundwaves to be emitted to the user.

25   The battery 270 is arranged to supply power to the various electronic circuits in modules 210, 220, 230 and 240. Preferably, the battery 270 is any commercially available rechargeable battery, such as a Li-ion, NiMH or NiCd battery.

30   The control block 240 comprises a microprocessor or CPU (Central Processing Unit) 242, which is bidirectionally connected to a memory 244. Among other functions, the CPU 242 controls the various components in blocks 210, 220 and 230, as well as an A/D converter 248,
35   by means of control signals indicated as unidirectional

arrows in FIG 2. More specifically, the components of the radio block 210, which consumes a majority of the total electric energy consumed from the battery 270, are controlled by the CPU 242 and an associated timing

5   generator 246 by means of respective pulsed control signals or "strobes". Consequently, a "TX str" strobe is supplied by timing generator 246, under control from CPU 242, to the transmitter 214. Similarly, an "RX str" strobe controls the receiver 212. A separate strobe controls the

10   A/D converter 248.

Up to this point, the architecture of the control block 240 as well as the operation thereof by way of different strobes are essentially identical to a standard GSM TDMA telephone.

15   According to the first embodiment, the control block 240 is provided with a strobe detector 247, which is arranged to detect the occurrence of strobes (i.e. control pulses having the purpose of switching specific circuits on and off) submitted by the timing generator 246 on

20   individual control lines, which extend between the timing generator 246 and the transmitter 214 and receiver 212, respectively, of the radio block 210. Simultaneously, the strobe detector 247 is arranged to read a momentary value of the digital control signal (DAC value) supplied to the

25   D/A converter 218 for controlling the output power level of the power amplifier 216. Additionally, the strobe detector 247 is arranged to count the number of TX strobes that have been generated for different output power levels (different DAC values). As will be described in more

30   detail below, these will be used by the CPU 242 to determine a consumption of charge from the battery 270.

Before providing a detailed description of the functions of the strobe detector 247 and the CPU 242 for determining aforesaid charge consumption value, the

35   inventive concept of using control signals or strobes for

the purpose of determining charge consumption will be
discussed next.

As already mentioned, a TDMA telephone uses a number
of control pulses or strobes, which are used to switch on
5   and off i.a. various radio circuits. The strobes are all
completely controlled by the CPU 242 in such a way, that
the telephone is capable of sending and receiving in the
correct TDMA timeslot. For instance, the TX strobe is
activated at least once for each TDMA frame in order to
10   switch on transmitter 214 and the components associated
therewith, such as the power amplifier 216. The trans-
mitter is activated, by the TX strobe, just before the
correct timeslot and is then deactivated immediately after
this timeslot, by switching the TX strobe from e.g. a high
15   logical value to a low logical value. In normal talk mode,
i.e. for a voice call, the TX strobe is generated exactly
once in every TDMA frame by the CPU 242 and the timing
generator 246, for as long as the ongoing telephone call
lasts. In case of a data call, on the other hand, the
20   number of TX strobes may be two or more (multislot) in
each TDMA frame. Simultaneously, as described above, the
CPU 242 determines a certain digital (hexadecimal) value
of the digital control signal DAC value, which is
converted into the analog control signal Pwr Ctrl used for
25   regulating the power amplifier 216 in order to obtain a
correct output power level of the transmitter 214.

Now, since the TX strobe activates/deactivates a
well-defined set of electronic circuits in the transmitter
214 and the power amplifier 216, and since the individual
30   charge consumption of each of these circuits is well-known
and/or may be accurately measured once and for all, with
respect to all possible DAC values, in a test laboratory
environment, the different DAC values are associated,
according to the invention, with respective predetermined
35   specific current consumption values, representing the

current consumed by all relevant transmitter and power
amplifier circuits upon activation by one TX strobe.

Consequently, by keeping track of the number of
times that the TX strobe has occurred for different DAC
5   values, the total current consumption, caused by TX
strobes during a given period of time, may easily be
calculated by multiplying the results of the count with
the predetermined current consumption values per TX
strobe.

10   As an important advantage, the inventive scheme
described above will be completely independent of whether
the telephone has been used for a voice call (involving
exactly one TX strobe per TDMA frame) or a data call
(multislot; possibly involving more than one TX strobe per
15   TDMA frame). The detector 247 will simply keep track of
all TX strobes, irrespective of in what frames they may
appear.

In addition to the above also the RX strobe and
other strobes may be monitored, such as an A/D strobe for
20   controlling the A/D converter 248.

Returning to the detailed description of the first
embodiment, the strobe detector 247 comprises a pulse
counter register 300 shown in FIG 3. Since the current
consumption during a TX strobe depends on the momentary
25   power level of the transmission (as set by DAC value), the
pulse counter register 300 comprises a plurality, or n+1,
of memory cells TxStrobe[00], TxStrobe[01], TX strobe[02],
... TxStrobe[n]. Each memory cell corresponds to a respec-
tive DAC value.

30   Initially, all memory cells are cleared, i.e. set to
0. Then, each time a TX strobe is generated by the timing
generator 246, the strobe detector 247 will increase the
memory contents at memory cell TxStrobe[i], where i
corresponds to the momentary transmission power level as
35   set by DAC value.

As already mentioned, a current consumption value is
associated with each memory cell in the pulse counter
register 300. These current consumption values, which
represent the respective amount of current consumed by

5   relevant electronic circuits upon activation by the TX
strobe for a particular DAC value, are stored in a current
consumption register 310. In similarity with the pulse
counter register 300, the current consumption register 310
may be located within the strobe detector 247, preferably

10 implemented as an EEPROM memory, or alternatively the
register may be stored in the conventional memory 244.

FIG 4 illustrates an algorithm for real-time
monitoring of TX strobes according to the first
embodiment. In this embodiment, the algorithm is executed

15 by the strobe detector 247. Upon initialization, all
memory cells TX strobe[] are cleared (set to 0) in a first
step 400. Next, a loop comprising steps 410, 420 and 430
is continuously executed. A step 410 monitors whether a TX
strobe has been detected. If no such strobe is detected,

20 the control is immediately transferred back to the
beginning of step 410. On the other hand, if the answer is
in the affirmative, a momentary DAC value is determined in
a step 420. Then, in step 430, the contents of the memory
cell TxStrobe [DAC value] is incremented. After that, the

25 control is transferred back to the beginning of step 410,
thereby forming an endless loop. In this way, the control
block 240 continuously monitors the occurrence of TX
strobes and reads the associated momentary DAC values so
as to keep track of the momentary current consumption

30 caused thereby.

FIG 5 illustrates an algorithm executed by the
control block 240 in order to determine an accumulated
charge consumption value and use this for determining the
remaining battery charge. As shown in step 500, an accumu-

35 lated current consumption value is calculated by multi-

plying all memory cells TxStrobe[00...n] in the pulse
counter register 300 with the corresponding memory cells
TxCurrent[00...n] of the current consumption register 310.
By summing the results of these multiplications and
finally multiplying with a predetermined duration $t_{TxStrobe}$ of
a transmit burst, a total accumulated charge consumption
value is obtained in step 500. This value is used in step
510 for determining the remaining battery charge,
preferably by subtracting the accumulated charge
consumption value obtained in step 500 with a previous
value of remaining battery capacity. Subsequently, in step
520, the battery icon 13 is updated on the display 6 to
reflect the updated remaining battery charge estimation.

A second embodiment is illustrated in FIGs 6-8. As
shown in FIG 6, the second embodiment uses a single
counter only (Current Count) instead of a table of
counters, thereby saving memory. A current consumption
register 610, holding predetermined current consumption
values, is still used.

An algorithm for real-time monitoring of TX strobes
according to the second embodiment is shown in FIG 7. The
current counter is reset or initialized in step 700. In a
step 710, it is monitored whether a TX strobe has been
detected. If the answer is in the affirmative, the control
is transferred to step 720, where the momentary DAC value
is determined. In step 730 the current counter is
incremented by the contents of the memory cell
TxCurrent[DAC value] of current consumption register 610,
in accordance with the momentary DAC value determined in
step 720. On completion of step 730, the control is
transferred back to the beginning of step 710.

FIG 8 illustrates an algorithm for updating the
battery indicator according to the second embodiment. In
step 800, an accumulated charge consumption value is
simply calculated by multiplying the transmit burst

duration $t_{TxStrobe}$ with the value of the current counter. In subsequent steps 810 and 820, the remaining battery charge is determined, and the battery icon 13 is updated on the display 6, in similarity with steps 510 and 520 of FIG 5.

5 Compared to the first embodiment, the second embodiment represented by FIGs 6-8 is more memory-efficient and also avoids multiplication by complete registers, thereby saving CPU power efficiency.

A third embodiment of the invention is shown in FIGs
10 9-11. For the third embodiment, the memory efficiency has been further improved. The size of the current consumption register 910 has been reduced as compared to the first and second embodiments. This will cause essentially no, or at least very little, loss in accuracy by using interpolation
15 to obtain a correct current consumption value. In simi- larity with the second embodiment, the third embodiment uses one single current counter, but the current consump- tion register 910 has been reduced in size by only storing a current consumption value for every eighth DAC value.
20 The current consumption register 910 is indexed by cal- culating idx-DAC value modulus 8. Two adjacent memory cells TxCurrent[idx] and TxCurrent[idx+1] are read, and these values are used for interpolating a correct current consumption value, as shown in the flow chart of FIG 10.
25 Steps 1000, 1010 and 1020 of FIG 10 are essentially identical to the corresponding steps of FIGs 4 and 7. In step 1030, as already mentioned, the index value idx is calculated as DAC value modulus 8. Then, in step 1040, a momentary current consumption value is obtained by linear
30 interpolation between the values TxCurrent[idx] and TxCurrent[idx+1], and the result thereof is added to the current counter. Subsequently, the control is transferred back to the beginning of step 1010.

The algorithm shown in FIG 11 for updating the
35 battery indicator is essentially identical to the

corresponding algorithms shown in FIGs 5 and 8 for the first and second embodiments, respectively.

According to yet another embodiment, the current consumption registers of the first, second and third embodiments may be replaced by a polynomial, which describes current consumption as a function of DAC value, for further improved memory efficiency.

The procedures above, which have been described in relation to the TX strobe, may be extended to other
10 strobes and circuits, such as the A/D converter 248, the channel encoder 222, the channel decoder 224, the speech encoder 232 and the speech decoder 234. The TX strobes described above all have a fix length in time and may consequently alternatively be stored directly in the form
15 of charge consumption values (expressed in mAh). However, for strobes that are variable in length, the predetermined consumption values may be stored as current consumption values (in mA), and the individual duration of such variable-length strobes will be determined by the CPU 242
20 or the strobe detector 247. For instance, such a variable strobe length may be determined by adding a signal with a well-known frequency in a register during the duration of the individual strobe. Upon execution of the procedures for determining total charage consumption shown in FIGs 5,
25 8 and 11 the content of such a register directly represents the total time during which the particular strobe has been active. By simply multiplying this time with the associated current consumption value, the charge consumption related to the strobe may be determined.
30 According to an alternative embodiment, a power consumption value is obtained by multiplying the calculated total charge consumption with a value of the battery terminal voltage.

The invention has been described above with
35 reference to a few embodiments. However, the present

invention shall in no way be limited by the description
above; the scope of the invention is best defined by the
appended independent claims. Other embodiments than the
particular ones described above are equally possible
5 within the scope of the invention. For instance, even if
according to the above embodiments the determination of
the total charge consumption is determined in both
hardware (strobe detector 247) and software (routine
executed by the CPU 242), the scheme may be implemented
10 solely in hardware, solely in software or partly in
software and partly in hardware. Moreover, the invention
is applicable also to other telephones than TDMA tele-
phones, such as W-CDMA telephones.